January 31, 1997

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Gloria Banchard, Grants Officer
Space Sciences Directorate Procurement Office
National Aeronautics and Space Administration
Goddard Space Flight Center - Code 216.1
Greenbelt, Maryland 20771

Dear Ms. Blanchard:

Enclosed is the final report for NASA grant NAG 5 3095, "Gamma-Ray Burst Model Constraints Imposed by BATSE Observations."

Sincerely,

Jon Hakkila
Professor of Astronomy

cc Teri Marshall
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Accessioning Department
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Dr. Jon Hakkila Final Technical Report on NAG 5 3095

January 31, 1997

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The investigative team for the CCRO Cycle 5 Guest Investigation "Gamma-Ray Burst Model Constraints Imposed by BATSE Observations" consisted of myself, Dr. Charles A. Meegan (NASA/MSFC), Dr. Geoffrey N. Pendleton (UAH), Dr. John M. Horack (NASA/MSFC), and Dr. Michael S. Briggs (UAH). The purpose of the research was to continue studying the BATSE gamma-ray burst angular and intensity distributions in order to better determine the gamma-ray burst distance scale.

During the course of this Cycle 5 investigation, new data analysis techniques were developed and statistical analyses were improved. Much of our focus changed from theoretical modeling to data analysis, as it became clear that some instrumental biases needed to be better understood before they could be used in determination of the gamma-ray burst distance scale. The BATSE Third Burst Catalog with its larger number of bursts and better burst locations provided the database for these analyses.

Burst Clustering/Repetition: In producing the 3B Catalog, we studied the two-point angular correlation function (TPAC) of the 3B Catalog and its published subsets (the 1B, 2B-1B, and 3B-2B). We found no evidence for clustering or repetition in the 1B and 2B-1B Catalogs (for which repetition was claimed), and only a marginal clustering signature (that could be simply a statistical deviation) in the 3B-2B and 3B Catalogs (Meegan et al. 1996). Using a complete multipole moment analysis (Tegmark et al. 1996), we found upper limits on the number of clusters in the 3B as well as on the number of bursts per cluster. These results were consistent with the null hypothesis of no clusters. Using a burst repetition model in which a pre-specified number of sources bursts randomly, we found limits on the mean repetition rate from examining both the TPAC and the burst pair dipole and quadrupole moments (Hakkila et al. 1996). Our updated statistical analysis showed that the burst pair diple and quadrupole moments cannot further constrain parameter estimation, but do place additional limits on the repetition/clustering hypothesis.

Constraints on the Luminosities of Cosmological Bursts: A standard $q_0=1/2$ Friedmann cosmology was assumed so that we could determine what constraints (if any) exist on the gamma-ray burst intrinsic luminosity function (modeled as a truncated power law with index β between minimum luminosity L_{min} and maximum luminosity L_{max}). As part of the investigation, we obtained a revised fit to the BATSE/PVO log(N>P) vs. log(P) curve, so that we could make use of the -3/2 (Euclidean) portion of the curve. We found that the luminosity function is in general unconstrained, with a limit of $L_{max}/L_{min} \leq 1000$ only near $\beta=2$ (Hakkila et al. 1996). Our updated statistical analysis used probabilites based on a formal χ^2

distribution for n free parameters. We were able to justify this result in terms of an analytical analysis (Horack, Hakkila, Emslie, & Meegan 1996), in which we demonstrated why some of the observed behavior occurs.

Internal Luminosity Function: We introduced a new technique for studying the distribution of luminosity within gamma-ray bursts for the fifty brightest gamma-ray bursts (Horack & Hakkila 1997). This distribution, which we call the internal luminosity function (ILF), can be approximated in many cases by a power-law functional form. The power-law index is found to correlate in a statistically significant way with both burst hardness and burst duration. This is a very useful result, as attempts to subclassify and correlate the properties of gamma-ray bursts have been made difficult by instrumental effects and by the large variation in burst intrinsic properties. We cannot positively say why the correlations exist, but they are consistent with gamma-ray bursts having fixed energy budgets.

Instrumental Biases: We developed an algorithm for calculating BATSE sky exposure and trigger efficiency, and began identifying databases needed to calculate 3B exposure and efficiency. The exposure and efficiency cannot be calculated for post-1B data sets in a manner similar to that used for the 1B Catalog, due to the presence of data gaps caused by failure of the onboard tape recorders. Upon coding and testing this algorithm, it will be possible to modify it for use on post-3B catalogs.

Publications and Papers Resulting from CGRO Cycle 5 Support:

Refereed Publications

1. "Luminosity Distributions of Cosmological Gamma-Ray Bursts", J. Hakkila, C. A. Meegan, J. M. Horack, G. N. Pendleton, M. S. Briggs, R. S. Mallozzi, T. M. Koshut, R. D. Preece, &W. S. Paciesas, (1996), *Astrophys. J.* **462**, 125-130.

2. "The Internal Luminosity Distribution of Bright Gamma-Ray Bursts and Its Relation to Duration and Spectral Hardness", J. M. Horack & J. Hakkila (1997), *Astrophys. J.*, in press.

3. "Analytic Constraints on Gamma-Ray Burst Luminosity Functions", J. M. Horack, J. Hakkila, A. G. Emslie, & C. A. Meegan (1996), *Astrophys. J.* **462**, 131-135.

4. "The Third BATSE Gamma-Ray Burst Catalog", C. A. Meegan, G. N Pendleton, M. S. Briggs, C. Kouveliotou, T. M. Koshut, J. P. Lestrade, W. S. Paciesas, M. McCollough, J. J. Brainerd, J. M. Horack, J. Hakkila, W. Henze, R. D. Preece, R. S. Mallozzi &G. J. Fishman (1996), *Astrophys. J. Supp.* (in press) and at WWW site http://cossc.gsfc.nasa.gov/cossc/batse/burstcatalog/3b_intro.html).

5. "The LogN-LogP Distribution for Bursts Observed by BATSE", G. N. Pendleton, R. S. Mallozzi, W. S. Paciesas, M. S. Briggs, R. D. Preece, T. M. Koshut, J. M. Horack, C. A. Meegan, G. J. Fishman, J. Hakkila, & C. Kouveliotou (1996), *Astrophys. J.* **464**, 606-615.

6. "Improved Limits on Gamma Ray Burst Repetition", M. Tegmark, D. H. Hartmann, M. S. Briggs, J. Hakkila, & C. A. Meegan (1996), *Astrophys. J.* **466**, 757-763.

Conference Proceedings

1. "Constraints on the Luminosities of Cosmological Gamma-Ray Bursts", J. Hakkila, C. A. Meegan, J. M. Horack, G. N. Pendleton, M. S. Briggs, R. S. Mallozzi, T. M. Koshut, R. D. Preece, & W. S. Paciesas (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 387-391.

2. "Repetition/Clustering in the BATSE 3B Catalog", J. Hakkila, C. A. Meegan, J. M. Horack, G. N. Pendleton, M. S. Briggs, D. H. Hartmann (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 392-396.

3. "The BATSE 3B Catalog", C. A. Meegan, G. N Pendleton, M. S. Briggs, C. Kouveliotou, T. M. Koshut, J. P. Lestrade, W. S. Paciesas, M. McCollough, J. J. Brainerd, J. M. Horack, J. Hakkila, W. Henze, R. D. Preece, R. S. Mallozzi &G. J. Fishman (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 291-300.

4. "Analytic Constraints on Gamma-Ray Burst Luminosity Functions", J. M. Horack, J. Hakkila, A. G. Emslie, & C. A. Meegan (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 412-416.

5. "Testing the Dipole and Quadrupole Moments of Galactic Models", M. S. Briggs, W. S. Paciesas, G. N. Pendleton, C. A. Meegan, G. J. Fishman, J. M. Horack, C. Kouveliotou, D. H. Hartmann, & J. Hakkila (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 335-339.

6. "EREBUS: An Experiment to Reveal the Burster Sites", C. A. Meegan, G. J. Fishman, B. A. Harmon, J. M. Horack, R. B. Wilson, J. J. Brainerd, M. S. Briggs, W. S. Paciesas, G. N. Pendleton, C. Kouveliotou, & J. Hakkila (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 856-860.

7. "Constraints on the Luminosity-Duration Relationship in the Galactic Scenario", R. E. Rutledge, W. H. G. Lewin, J. Hakkila, G. N. Pendleton, J. P. Lestrade, C. Kouveliotou, C. A. Meegan, & G. J. Fishman (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 517-521.

8. "Search for Constraints on the Peak Flux-Distance Relation in the Cosmological Scenario", R. E. Rutledge, W. H. G. Lewin, J. Hakkila, T. M. Koshut, G. N. Pendleton, J. P. Lestrade, C. Kouveliotou, C. A. Meegan, & G. J. Fishman (1996), in *Proceedings of the 1995 Huntsville Gamma-Ray Burst Symposium*, p. 522-526.

Published Abstracts

1. "On the Distribution of Luminosity Within Cosmic Gamma-Ray Bursts", J. M. Horack, J. Hakkila, R. D. Preece, T. M. Koshut, & R. S. Mallozzi (1996), *Bull. Amer. Astron. Soc.* (abstract, in press).